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The U.S. Army Topographic Engineering Center (TEC) has assembled a fully integrated digital image-based mapping system called the Terrain Information Extraction System (TIES). This paper evaluates the photogrammetric GIS technology on the TIES.

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PHOTOGRAMMETRIC GIS TECHNOLOGY: FEATURE MAPPING ON DIGITAL STEREO IMAGERY

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ABSTRACT

Geographic Information Systems (GIS) contain functions to process the spatial and attribute data of a map. Digital-Photogrammetric systems contain functions to aero-triangulate and visualize digital stereo imagery, rectify imagery, and create Digital Terrain Matrixes (DTM). Integration of GIS and Digital-Photogrammetric systems allows digital feature data processing on the most current stereo imagery. Such "photogrammetric GIS" technology enables more reliable imagery measurements than two-dimensional GIS technology which only allows horizontal feature extraction from a single image. The single image usually retains geometric distortions from its original exposure complicating the mensuration and delineation of objects in the map.

The U.S. Army Topographic Engineering Center (TEC) has assembled a fully integrated digital image-based mapping system called the Terrain Information Extraction System (TIES). This paper evaluates the photogrammetric GIS technology on the TIES.

SCOPE

Photogrammetric Geographic Information System (GIS) components are described. The Terrain Information Extraction System (TIES) photogrammetric GIS technology is evaluated by describing the TIES GIS components, and by describing the TIES data characteristics, quality, and standards.

PHOTOGRAMMETRIC GIS COMPONENTS

A Geographic Information System (GIS) is defined as "a system of computer hardware, software, and procedures designed to support the capture, management, manipulation, analysis, modeling, and display of spatially referenced data ..." (Federal Interagency Coordinating Committee on Digital Cartography 1988). We will refer to that as GIS processing of digital feature data. Photogrammetric technology enables more reliable measurements from imagery. A photogrammetric GIS is a triad of subsystem functions which use GIS processes on digital imagery and digital feature data (see Figure 1).

Digital Imagery and Digital Feature Data

A digital image is a uniform grid of discrete rectangular picture elements called "pixels" with brightness values assigned to each grid cell. Each digital image includes a

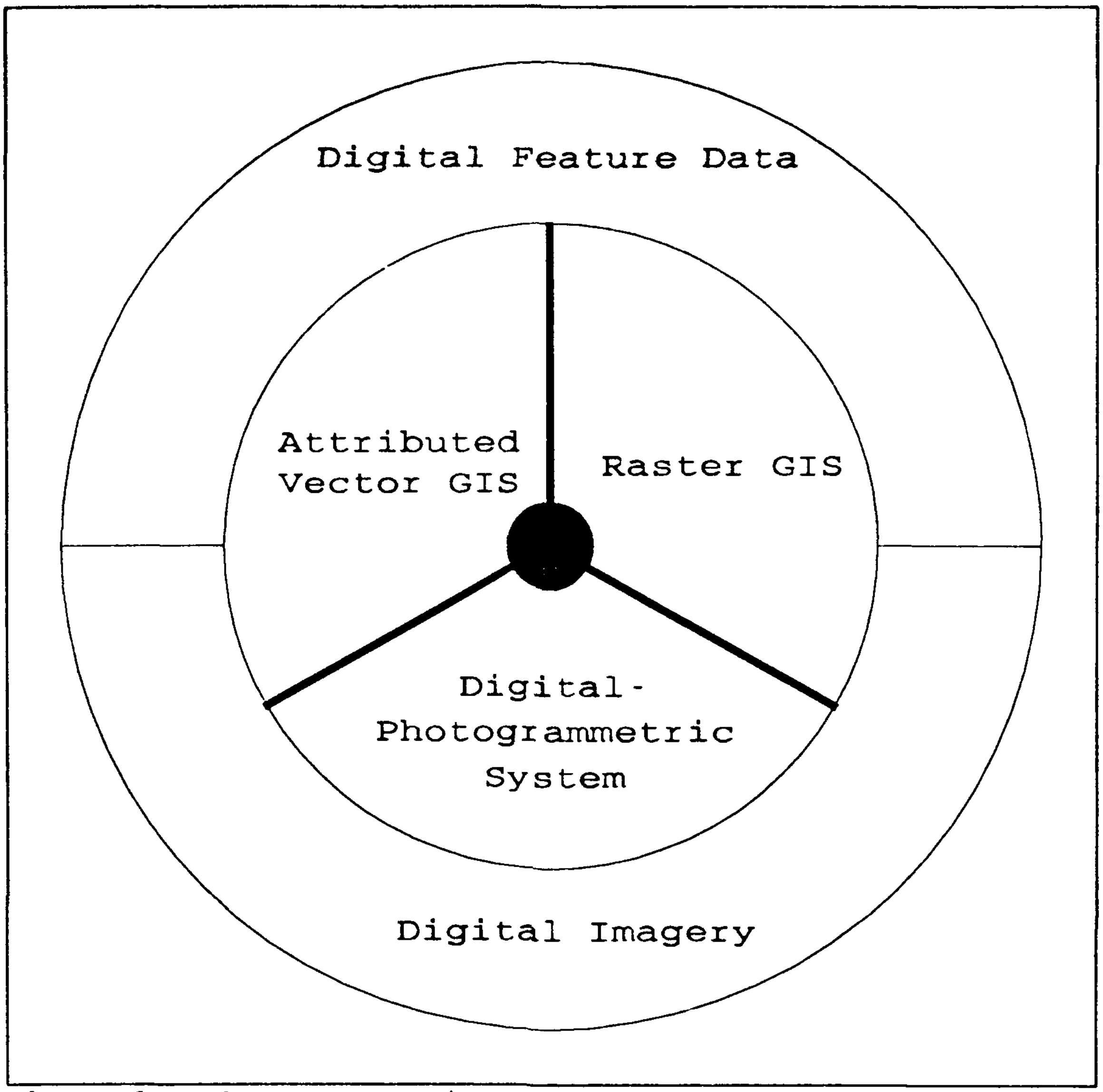

Figure 1: Photogrammetric GIS Components

file of geometric support data including sensor attitudes (exposure parameters, and estimated positions and orientations) and ground control points.

The processing of digital feature data is frequently called feature mapping. Digital feature data are defined as a set of delineated and described objects. Objects are identified with spatial and attribute data. Spatial data delineate each object. Attribute data describe each object. A Digital Elevation Model (DEM) surface can be digital feature data of elevation points, of elevation lines (contours or profiles), or of elevation surface facets (connected area features).

The digital formats facilitate analytical processing of the combined imagery and feature data, where the image texture enhances the interpretation of the feature data.

<u>Delineation</u>. Spatial delineation occurs by producing a string of [x,y] or [x,y,z] coordinates called an arc. Each arc consists of sequentially pair-wise connected coordinates in arc-node topology. The coordinates are connected by simple curved splines or straight line segments. Nodes are the end-points of each arc. A single coordinate is a point feature.

An arc is the center-line of a line feature, and/or the shared edge of two contiguous area features. The surface of a solid object may be formed by connected area features to form a volume feature, where the area feature edges are called the "wire-frame" of the object.

Nodes are created at the horizontal intersection of two arcs in two-dimensional topology. Nodes are stacked on top of each other when the features intersect horizontally but not vertically in two-and-a-half-dimensional topology. Volume features are described by unions and intersections of connected area features which are surface facets of solid objects in three-dimensional topology.

Attribution. A list of attribute items is created for each object in the digital feature data. Each attribute record contains a unique set of attribute item values describing a delineated object in the digital feature data. The spatial data contain pointers to attribute records in the digital feature data.

Image Analysis. Image analysis includes the delineation and attribution of objects contained in the imagery to create digital feature data. Textbooks such as Remote Sensing and Image Processing (Lillesand & Kiefer 1979) describe image interpretation techniques. Textbooks such as Digital Image Processing (Castleman 1979) describe automatic digital image analysis techniques.

Interactive image analysis occurs in a computer-assisted environment by providing computer graphic tools for an analyst to draw point, line, area, and volume features on a raster image, or on a raster digitized map, at an image processor display device. Computer tools are provided for an analyst to process attribute records in a relational data base describing delineated objects. The analyst is provided a "code list" from which to pick values for attribute items described in an "extraction specification."

Automatic image analysis occurs in a raster GIS by identifying image areas where there are common photo properties, for example by identifying common combinations of sensor responses between different spectral bands. If the sensor incident energy (brightness) is split into separate spectral bands, then an automatic spectral analysis can be done to classify each grid cell. Those spectral characteristics are used to identify objects in the imagery, by using a knowledge base already containing a set of representative objects.

Raster-to-vector conversion utilities must exist to segment the digital feature data grid from the raster GIS for subsequent processing by the attributed vector GIS.

Digital-Photogrammetric Systems

A Digital-Photogrammetric system contains functions to rectify digital imagery by using the sensor math model and the projective equations, for projections between the imagery and the Digital Elevation Model (DEM) surface. Digital image rectification samples the image grid to geometrically reshape the image. Aero-triangulation adjusts the geometric support data for consistent solutions to photogrammetric equations. Digital stereo imagery can be used to process DEM surfaces.

All of those functions are unique to the Digital-Photogrammetric system in a photogrammetric GIS.

Geometrical image distortions are caused by the sensor interior and exterior orientations, and by terrain displacement. The ability to rectify digital imagery by removing geometrical image distortions permits accurate visualization, mensuration, and delineation of objects in a three-dimensional coordinate frame from stereo imagery. Textbooks such as Photogrammetry (Moffit & Mikhail 1980) contain detailed explanations of those photogrammetric functions.

Stereo Visualization. Differential parallax occurs because of different projective geometry from overlapping image planes. The Human Visual System (HVS) perceives depth when it fuses a pair of images (one seen in each eye) with differential parallax. An image processor display system with a polarized viewing mechanism is necessary to view the digital stereo imagery.

The HVS has difficulty fusing stereo imagery throughout the complete field of view unless the imagery has been rectified to have projective geometry similar to vertical frame photography where all image scale distortions are removed except those caused by terrain displacement, and where each stereo image has identical pixel ground-sample-distance. In fact, an imagery auto-correlator has difficulty matching images (by using normalized cross correlation techniques) to develop a DEM unless terrain displacement is the only cause of differential parallax between images. Such vertical frame camera geometry can be created using both the sensor math model and the projective equations to rectify the image by projecting it onto a flat (constant elevation) DEM surface.

Image Perspective Transformations. An Image Perspective Transformation (IPT) enhances Computer Image Generation (CIG) by "reflecting" original imagery texture off the DEM surface towards viewpoints different from the sensor position during image exposure. The IPT is a sophisticated technique for rectifying digital imagery. The perspective view is created by using a frame camera math model from the new viewpoint, or by "draping" the images and feature data on a perspective transformation of the DEM surface, including "wire-frames" of solid object surface facets which may (or may not) exist in the original imagery. A sequence of the IPT frames from a path of viewpoints can be used to produce an animated view. The IPT gives more realistic views for mission rehearsal by using actual image texture.

Geographic Information Systems

The typical attributed vector Geographic Information System (GIS) or raster GIS contains software functions to process the objects in the digital feature data. A GIS may have the capability to do interactive processing of the digital feature data with a single image "back-drop." However, photogrammetric functions to correct geometrical image distortions do not exist in the typical GIS, because the GIS does not contain a mathematical model for the sensors exposing the imagery, or for projections between imagery and the Digital Elevation Model (DEM) surface. A GIS which ignores

photogrammetric principles does not allow accurate feature mapping on digital stereo imagery. Rubber-sheeting is not considered to be a photogrammetric function. A GIS can process DEM surfaces as digital feature data of elevation points, lines (contours or profiles), or facets (connected area features).

Attributed Vector GIS. An attributed vector GIS contains functions to process spatial topology and attribute relationships of objects in the digital feature data. The attributed vector GIS has functions to combine information from several overlaid digital feature data sets, and to mosaic adjacent digital feature data sets together.

Raster GIS. A raster GIS uses analysis functions to process data grids, where each grid cell is an attributed feature. Spatial analysis occurs when a grid cell value depends on the grid cell values in the neighborhood of the corresponding grid cell.

A raster GIS may do automatic image analysis. Automatic image analysis occurs where the digital image is a grid of brightness values (of energy incident on the sensor during image exposure). The raster GIS may do automatic image analysis by using functions which analyze and adjust the digital image radiometry. The image radiometry includes image brightness properties in both the spatial and frequency domains, so frequency analysis functions are also used for automatic image analysis in addition to spatial analysis functions. Both spatial and frequency analysis involve matrix-like operations on the image grid, so both types of analysis will be considered raster GIS functions despite their dichotomy.

TIES GIS COMPONENTS

The Terrain Information Extraction System (TIES) is a fully integrated digital stereo image-based mapping system which uses photogrammetric Geographic Information System (GIS) technology. The Topographic Engineering Center (TEC) intends to use the TIES as a test-bed for developing Army digital image-based mapping capabilities.

The TIES accomplishes feature mapping on digital stereo imagery with photogrammetric GIS processing of digital data files exchanged among several subsystems (see Figure 2).

Digital Data Files

Each TIES subsystem has its own computer. The subsystems exchange digital data files over an Ethernet with the UNIX "telnet" and "ftp" commands using the TCP/IP protocol.

Digital-Photogrammetric System

The Digital Stereo Photogrammetric Workstation (DSPW) is the TIES Digital-Photogrammetric system. The DSPW was developed under contract for the TEC. The DSPW is capable of managing and displaying digital imagery and its geometric support data, of aero-triangulating digital imagery, of rectifying digital imagery, of automatically creating Digital Terrain Matrixes (DTM) at any specified elevation point spacing (by using a

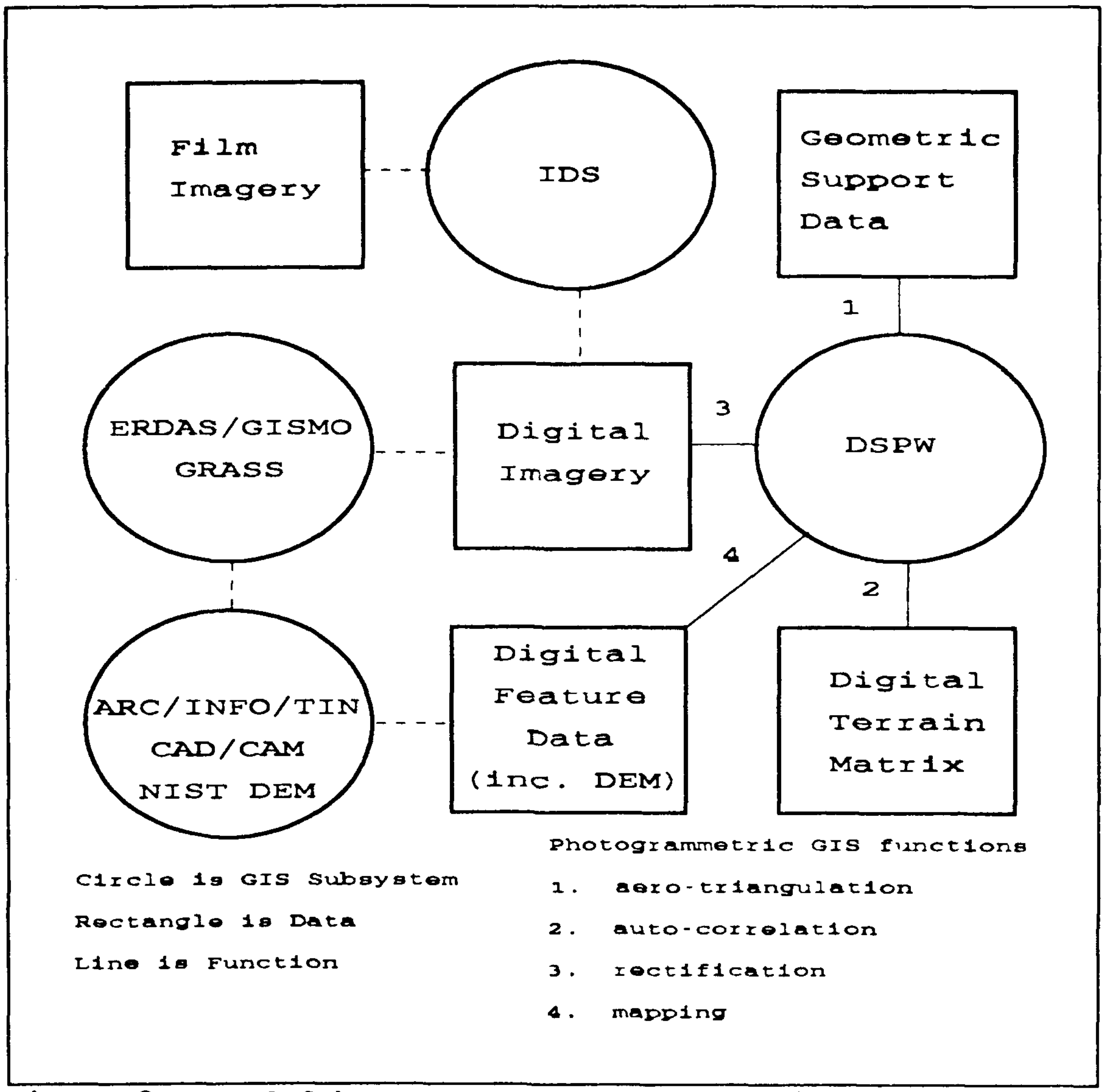

Figure 2: TIES Subsystems, Data, and Functions

digital imagery auto-correlation technique), of interactively editing a DTM on stereo imagery, and of displaying and interactively editing digital feature data which are stereoscopically superimposed on stereo imagery. The DSPW software can be used to interpolate an elevation from a DTM for each digital feature data [x,y] coordinate so the digital feature data can be stereoscopically superimposed on the digital stereo imagery. An Image Perspective Transformation (IPT) capability is being added to the DSPW. The aero-triangulation, auto-correlation, and image rectification functions are unique to the Digital-Photogrammetric system in a photogrammetric GIS.

The DSPW uses the graphics user interface of OSF/Motif windows to control the photogrammetric processing at a "control" monitor. The image processor is the VITec-10. The "extraction" monitor is the Tektronix SGS625 Stereoscopic Display System device with a liquid crystal shutter. The stereo image is produced on the device by alternating the display of a pair of overlapping images at 120 Hertz. The stereo image is viewed on the monitor with circularly polarized viewing glasses. Horizontal and vertical motion on

the stereo image is controlled with a pair of track-ball devices.

Attributed Vector GIS

The attributed vector GIS is intended to be the TIES feature data repository. The TIES attributed vector GIS does automatic spatial and relational processing of the digital feature data. The current attributed vector GIS for the TIES is ARC/INFO/TIN. ARC/INFO/TIN is a commercial software system. ARC/INFO/TIN is being used as the TIES repository for digital feature data, and for Digital Elevation Model (DEM) surfaces (elevation lattice, lines, and facets). DEM surfaces are converted to digital feature data by ARC/INFO/TIN, so they can be stereoscopically superimposed on stereo imagery at the DSPW. A Computer Assisted Drafting-Modeling (CAD/CAM) system may be considered for processing volume features in digital feature data because ARC/INFO does not have three-dimensional topology. DEM surface processing software is being developed by the National Institute of Science and Technology (NIST) for the TIES.

Raster GIS

The TIES raster GIS analysis software systems include the ERDAS/GISMO (Earth Resources Data Analysis System & GIS Modeling), and the GRASS (Geographic Resources Analysis Support System). The ERDAS is a commercial raster image analysis software system. GISMO is the ERDAS grid spatial analysis software. The ERDAS/GISMO will be used in the future to accomplish automatic image analysis, which can be verified and edited on stereo imagery at the DSPW once the feature data grid is converted to attributed vectors. The GRASS is public-domain grid spatial analysis software.

Image Scan-Digitizing System

The Image Digitizing System (IDS) converts photographs to digital images. The scanner is a precise continuous scanning optical device consisting of a 1-by-2048 array of charge coupled micro-sensors. The scan resolution is selected to equal 7.5 micrometers times exponential powers of two (7.5, 15.0, 30.0, 60.0, 120.0, ...). The IDS was developed under contract for the TEC. The precise scanning instrumentation was built by an IDS subcontractor.

TIES DATA CHARACTERISTICS, QUALITY, AND STANDARDS

The Terrain Information Extraction System (TIES) data characteristics, quality, and standards are described.

Data Characteristics

Each TIES subsystem supports a variety of standard industry data formats. In addition, generic digital imagery and digital feature data text file formats have been developed for exchanging digital data among the TIES subsystems. Those files are human interpretable without using special translation software, except for the binary image pixel data.

Digital Imagery. An Image Exchange Format (IEF) has been developed which consists of a text formatted key-word-then-value(s) header file containing the geometric support data necessary for photogrammetry, and a binary formatted 8-bits-per-pixel image pixel file. Imagery data exceeding 8 bits per pixel needs to be converted to 8 bits per pixel for the TIES. The pixels in the image are "tiled" into 128-by-128 data blocks. Then the left-to-right rows of tile blocks are sequentially stored as "ordered-tiles" starting at the upper-left-hand corner of the image. The Digital Stereo Photogrammetric Workstation (DSPW) sequentially stores and displays the rows of 128-by-128 pixel blocks with a VITec-10 image processor and Tektronix Stereoscopic Display System. DSPW software routines exist to convert between the tiled image format and raster format where rows of pixels are sequentially stored. The raster image format is necessary to exchange imagery between the DSPW, the ARC/INFO Geographic Information System (GIS), and the ERDAS image analysis system.

Digital Feature Data. The TIES feature data repository is ARC/INFO/TIN which is an attributed vector GIS with two-dimensional topology. The ARC/INFO/TIN Surface Modeling and Display software functions are being considered to process feature data with [x,y,z] coordinates, so the DSPW need not convert [x,y] coordinates back to [x,y,z] coordinates. Otherwise the elevation values from the [x,y,z] coordinates are lost during ARC/INFO processing of the digital feature data. There is a concern that the ARC/INFO/TIN data structures may be incompatible with volume feature data which requires three-dimensional topology. Computer Assisted Drafting-Modeling (CAD/CAM) systems may be considered for processing volume feature data (formed by solid object surface facets which are connected area features).

An attributed vector GIS "funnel" concept was developed to prevent an unmanageable proliferation of TIES digital feature data formats. Any digital feature data gets deposited in the TIES attributed vector GIS (because of its ability to do spatial and attribute processing). That concept led to the development of a TIES Feature Map Exchange Format (FMEF). The TIES-FMEF is used to exchange data between ARC/INFO/TIN and the DSPW. The TIES-FMEF is in an ASCII text file format, so the data are human interpretable.

The chosen formats for the TIES-FMEF are the ARC/INFO "generate" format for the spatial data, and the ARC/INFO "items" and "list" formats for the attribute data. The "generate" format is a text file consisting of a feature identification number followed by a string of either [x,y] or [x,y,z] coordinates. The "list" format is a text file in a flat table format consisting of a row of ordered feature attribute values for each object in the digital feature data, with white-space delimiters between each attribute item value. Each column of the table is a particular attribute item in a relational data base. The "items" format is a text file describing the format for each particular attribute item (commonly called the "extraction specification") in the relational data base. The Geographic Information System Software ARC/INFO Users Guide (Environmental Sciences Research Institute 1989) describes those formats.

Data Quality And Standards

The TIES produces accurate and precise digital data because it uses photogrammetric GIS processing of digital feature data in a digital stereo image-based mapping environment. The TIES can be used to identify various inconsistencies between separate data sets, or to ensure that those inconsistencies never occur during data collection. Identified inconsistencies can be corrected at the TIES.

CONCLUSION

The primary purpose of the Terrain Information Extraction System (TIES) is to process digital imagery and digital feature data including Digital Elevation Model (DEM) surfaces. As such, the TIES can be used as the primary instrument for processing map information. The TIES can collect data which is not available from large government mapping agencies such as the Defense Mapping Agency or the United States Geological Survey.

Photogrammetric Geographic Information System (GIS) technology allows the TIES to accomplish digital stereo image-based mapping. Current and future developments on the TIES will provide the Army with a fully integrated digital image-based mapping system.

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